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OCEAN SUN GLINT IN THE 8 TO 12 MICRON REGION AND ITS RADIANCE VARIATION WITH OFF GLINT SUN ANGLE AND SENSOR ELEVATION

BY MONTE S. KAELBERER

RESEARCH AND TECHNOLOGY DEPARTMENT

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NAVAL SURFACE WARFARE CENTER
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FOREWORD

This report describes analyses of sun glint data collected with the Background Measurement and Analysis Program (BMAP) sensor during the mid-1980's. All available data taken with the BMAP infrared radiometric sensor operating in the 8 to 12 micron region was compiled and searched for appropriate sun glint scenes. The data was used to find the variation in average and standard deviation radiance due to different off glint angles and sensor elevations.

This research analysis task was performed while on a detail assignment from the Sensors Technology Branch, Code R43, to the Radar Engineering Branch, Code F43, during the period from July 1990 through September 1990. The author would like to thank Mr. D. G. Kirkpatrick, Code F43, for his help and supervision throughout the assignment.

Approved by:

C. W. Larson

C. W. LARSON, Head
Radiation Division

ABSTRACT

Ocean sun glint data taken in the 8 to 12 micron region with the Background Measurement and Analysis Program's (BMAP) infrared radiometric sensor was compiled and reduced. The average radiance and standard deviation for each sensor scan was calculated and graphed against the sun glint angle and the sensor elevation.

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INTRODUCTION

Because the 8 to 12 micron region of the infrared (IR) spectrum is an area of good transmission, it is a commonly used bandpass for IR sensors. While this IR window may allow the sensor to see through the atmosphere better than others, there still may be naturally occurring IR clutter in the background. This clutter can easily interfere with the detection of a predefined target. One type of IR clutter is the sun's reflection from water surfaces onto the IR detector. This sun glint or ocean glint was shown in an earlier report to seriously affect sensors operating in the 3 to 5 micron region[1]. The next step is to determine what effect, if any, sun glint has in the 8 to 12 micron region. The motivation for this analysis is to acquire a quantitative database of actual glint data which can later be compared with sun glint models.

Sun glint has many parameters that can affect its intensity and the size of its pattern. Some examples are sea slope, off glint angle, sun elevation, sensor height above the water, sensor elevation angle, atmospheric absorption and scattering, wind speed, clouds, and water and air temperatures. Figure 1 is an illustration of some of the parameters that will be examined in this report, for example, off glint angle and sensor elevation. The Background Measurement and Analysis Program (BMAP) has a collection of sun glint scenes from field tests done in the period 1983 to 1986. The collection covers parameters affecting sun glint such as geographic location, off glint angle, sensor elevation angle, and sun elevation angle. These parameters and other terms are briefly explained in the Nomenclature. Planck's blackbody function shows that the contribution by sun glint to the energy seen by the sensor in the 3 to 5 micron region (midwave) will be greater than in the 8 to 12 micron region (longwave). This report uses average and standard deviation statistics to determine the degree to which sun glint affects the longwave region and to observe the change in sun glint with different off glint angles and sensor elevations. Well-known IR principles are then applied to the data to explain the structure and trends which are evident in each scene.

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[1] Kaelberer, M. S., Ocean Sun Glint in the 3 to 5 Micron Region and Its Radiance Variation with Off Glint Sun Angle and Sensor Elevation, NSWC TR 90-74, Mar 1990, NSWC, White Oak, MD.

RAYTHEON/BMAP SENSOR

The BMAP sensor is an IR, scanning radiometer manufactured and owned by the Raytheon Company of Tewksbury, Massachusetts. It uses two, 16-detector focal plane arrays (FPA). One FPA is for midwave operation, and the other is for longwave operation. The 16 detectors, along with the scanning mirror, have a total field of view (TFOV) of 2.5 degrees in azimuth by 0.3 degree in elevation. The TFOV includes the scanning of internal reference sources. Each detector has an instantaneous field of view (IFOV) of 0.33 milliradian in azimuth and in elevation. The noise equivalent irradiance (NEI) of the sensor is 1.5×10^{-14} watts cm^{-2} in the midwave and 2.0×10^{-13} watts cm^{-2} in the longwave.

The midwave filter has a full-width, half-maximum (FWHM) bandpass of 3.9 to 4.8 microns. The FWHM points for the longwave filter are 7.6 to 11.6 microns. Midwave data is not used in this report. During the operation of the sensor, data can be collected only when the scanning mirror travels in one direction. The mirror makes one scan and its return in 0.5 second (one period) with no data collected on the mirror's return. The most common mode of data collection records alternating scans of midwave and longwave data. Most of the scans in this report used the alternating mode of operation making the longwave scans of a scene 1 second apart. The sampling rate of the detectors is such that a point source is sampled 3.4 times in 1 IFOV. In a typical scan there are 360 to 370 samples creating a total image azimuth of about 2.0 degrees.

FIELD SITES

Sun glint data was available from three different geographic locations. Most of the data available was taken at the Wallops Island Detachment of the Naval Surface Warfare Center in Wallops Island, Virginia. The length of the test was from 27 May through 5 June 1986. The BMAP sensor was placed on a rooftop at a height of 19 meters and at a distance of 180 meters from the beach. The coordinates were 37 degrees 50 minutes north and 75 degrees 29 minutes west. For some scenes at Wallops Island the sensor was tipped on its side causing the scanning mirror to scan along elevation rather than along azimuth. The TFOV is then 2.0 degrees in elevation and 0.3 degree in azimuth.

Radiosonde data was taken each day at Wallops Island by Wallops Island Detachment personnel at 0 GMT and 1200 GMT. The radiosonde data measured temperature, pressure, humidity, and wind speed. The Wallops Island IR data used in this report is from two different days and was taken between the times of 0700 EDT and 0900 EDT. The radiosonde data of 1200 GMT should, therefore, give a good indication of the general weather conditions at the time the data was collected. Table 1 lists the meteorological conditions for the 2 days of interest. The values were selected from a radiosonde altitude of 13 meters.

Also used at Wallops Island was a waverider buoy. The output of the buoy was an analog trace of time versus wave height. Analysis of the traces at the time of data collection showed maximum wave heights (measured from wave minimum to wave maximum) of 0.5 meter for 30 May and 2.2 meters for 3 June. Rough average wave height estimates for 30 May and 3 June were about 0.05 meter and 0.2 meter, respectively.

Sun glint data was taken at Fort Walton Beach, Florida, from 29 May through 7 June 1985. The sensor was operated from the balcony of a fifth-floor condominium with a latitude and longitude of approximately 30 degrees 24 minutes north and 86 degrees 37 minutes west, respectively. The exact height of the sensor was unavailable but is assumed to be between 20 and 25 meters above sea level. Table 1 lists the radiosonde measurements taken at a height of 20 meters which were collected at Eglin Air Force Base. IR data at this location was taken during late afternoon.

The BMAP sensor attended the NATO RSG-5 Common Sea Background Trials at Toulon, France, which were held from 9 October through 16 October 1985. The sensor was placed on a 45-meter cliff which faced in the direction of 240 degrees east of true north and overlooked the Mediterranean Sea. The ground level weather measurements taken at the sensor site with hand-held instruments are shown in Table 1. The IR data and weather data were taken at about 1430 local time.

DATA LIMITATIONS

Raw BMAP data was processed by the Naval Research Laboratory (NRL), Washington, D.C. Their task was to calibrate the data, correct bit errors, flag dead detectors, add a NATO header onto each scan, and put the data onto 9-track computer tapes. Of the three field sites, only Fort Walton Beach had bit errors. Each scan had, on average, 20 errors which were corrected.

The first detector in the longwave FPA was dead and could not be used in any calculations. Some scenes had boats, the horizon, or other non-water backgrounds in them in which case the statistics for those scenes were calculated by omitting those sections containing the objects.

Data points are stored on tape as 2-byte integers. The integers are converted to radiance by factors given in the NATO headers of each file. The factors in some of the Toulon data were recognized as obviously incorrect, but since the header factors in the Toulon data that was not corrupted were equal to those used for Fort Walton Beach and Wallops Island, the same radiance factors were used for all the Toulon data.

During the Wallops tests the time code signal used to mark the data sometimes became partially scrambled making some of the scans untraceable. Fortunately the scenes used in this report had their time codes intact, and identification was not a problem.

A factor shrinking the pool of available scenes was the limited amount of sun glint data that had been requested from NRL. While many different scenes of sun glint had been taken at each field site, only a fraction had been reduced to the 9-track tape format. Additional raw data of sun glint could not be acquired because NRL no longer processes raw BMAP data.

REDUCTION METHOD

For scenes with horizontal scanning, the scan was divided into three sections of equal size. The average and standard deviation radiance was then found for each section. Because channel 1 was dead, all sections (without obstructions) used channels 2 through 16. The first section represented samples 1 to 50; the second section, samples 155 to 205; and the third section, samples 310 to 360. Vertical scans were divided differently. Each section still used 15 channels, but now the sample widths were 1 to 50, 51 to 100, 101 to 150, and so on. Figure 2 shows the partitioning of the sections in both horizontal and vertical scans. The section sizes were chosen to have an approximately square field of view of 0.3 degree to a side.

A total of 27 different scenes were examined. Each scene had approximately 10 scans so a total of about 270 scans was compiled. Many scenes were actually parts of runs. There were 7 runs in the compiled data, and all were at Wallops Island. The scenes from Toulon and Fort Walton Beach were not associated with any runs. Four runs were scenes with horizontal scanning, and three runs were scenes with vertical scanning. The first horizontal scanning run held the sensor at a 0 degree sensor elevation and then took data at off glint angles of 0, 5, and 10 degrees. The other three horizontal runs did the same but at sensor elevations of -1, -2, and -3 degrees. There were two vertical scanning runs which held the sensor elevation at 0 degree and then took data at off glint angles of 0, 5, and 10 degrees These runs differ in that they were done about 1 hour apart. The other vertical scanning run was done similarly but at a sensor elevation of -1 degree. Table 2 shows what scenes were used and their associated parameters. The sensor elevations for vertical scanning scenes in Table 2 represent the elevation at mid-scan (sample 180). Sensor elevations for horizontal scans refer to the elevation of the middle channel.

In horizontal scanning scenes a sensor elevation of 0 degree has the sky in the upper channels. The average and standard deviation radiances for these sections were found using only channels 13 through 16 which were always below the horizon. Vertical scans always contained the horizon, in which case only the sections below the horizon were used.

Tables 3 and 4 show the minimum, maximum, and midrange statistics for each scene. The average and standard deviation radiance for each section in a scan was calculated and compared with the other scans from that scene. Then the minimum and maximum statistic was found for each section within the scene. The range (maximum minus the minimum) within a section was typically very small as is clear in Tables 3 and 4. The midrange ((maximum + minimum)/2) rather than the scene section average was used because the range was small and it was more efficient in the use of available computation time. For example, the Wallops scene with a glint angle of 5 degrees and sensor elevation of -1 degree had five scans with radiance averages for section one of 23.39, 23.39, 23.40, 23.41, and 23.38 W m^{-2} sr^{-1}. For this scene the midrange and the average of the section averages are 23.395 and 23.394 W m^{-2} sr^{-1}, respectively.

Note that horizontal scans have three sections. Because the field of view is approximately 2 degrees, the middle section is taken to be the off glint angle of the scene in Table 2, and the right and left sections will be one plus and minus the off glint angle, respectively. The actual offset is closer to plus and minus 0.83 degree but will be shown as 1 degree in the figures. The sensor elevation for a vertical scan was determined by letting the section with the horizon be at 0 degree, and the sensor elevation for each lower section was decreased by 0.33 degree.

ANALYSIS

Figure 3 is a graph of the midrange radiance values from Tables 3 and 4 versus the off glint angle. The numbers and boxes used as points in the graph represent the sensor elevation of each point. A box was used to represent a sensor elevation of 0 degree, and numbers are the negative of the actual sensor elevation. Sensor elevations of -2 degrees have been offset horizontally by a small amount to make the elevation values more readable. The location from which each group of points was collected is indicated by the text in the graph.

Figure 3 has an obvious stratification of the data where the range of radiance values for each field site are separate and distinct. The reason for the stratification is linked to the ambient temperature of the atmosphere which is a major contributor to the radiance seen at the sensor. In the context of this report there are three primary IR sources contributing to the radiance. The atmosphere between the sensor and the water can radiate as a blackbody at the ambient temperature in select wavelength regions if it is optically dense enough and of sufficient length. The water can radiate as a blackbody at the water temperature, but since the sensor elevations in this report are shallow, the water will also be a good reflector and only a fraction of the energy emission from the water will make it to the sensor. The IR sources that can reflect from the water would be of the sky, the clouds, or the sun (glint). Review of the meteorological observations made at the field sites revealed that there was little or no cloud cover. Table 1 showed relatively low wind speeds for all field sites. This implies a fairly calm water surface which will mostly reflect only objects slightly above the horizon. In addition, calm seas would certainly be the case for Wallops Island as seen from the waverider buoy analysis. The sun elevations examined are all above 20 degrees, and this suggests that reflections from the water surface are going to be primarily of the sky (or lower atmosphere).

Using Table 1 and assuming field sites with a higher ambient temperature will have a higher radiance, Fort Walton Beach should have the highest radiance followed by Toulon, the horizontal scans of Wallops, and finally the vertical scans llops. The actual order of the radiance from each field site in Figure 3 has the Toulon and Fort Walton Beach data transposed. For these two sites, other parameters start affecting the radiance seen by the sensor. One parameter is the length of path the sensor must see through at each site. Since Wallops Island and Fort Walton Beach each had a sensor height of about 20 meters while Toulon was at a height of 45 meters, Toulon had a much longer path to look through. This would tend to increase the radiance contribution from the atmosphere.

Another parameter that affects the apparent temperature is the absolute humidity. Typically an atmosphere with a high absolute humidity will have a radiance closer to the ambient temperature than an atmosphere with a lower absolute humidity. Table 1 shows no correlation between the humidity and the radiance suggesting for this data that the humidity was not as important as the length of path.

Table 5 gives the radiance a blackbody would have between 7.6 to 11.4 microns if it was at the indicated temperature. The radiances were calculated by numerically integrating Planck's Law at the given temperature and wavelength limits. Using Table 5, the radiance axes in the figures can be converted to apparent temperature. In Figure 3 the radiance range of about 18.0 to 30.0 W m^{-2} sr^{-1} converts to a temperature range of -10 to 16 degrees Celsius. Apparent temperatures this low imply that the transmission of the atmosphere is fairly high and that, since the water temperature is not near those temperatures, the water must be acting as a reflector of the sky. But again since the atmosphere is quite transmissive, the sky does not add much to the radiance and thus the total radiance at the sensor produces a relatively low apparent temperature. This differs from the results in the report on the midwave IR in which the apparent temperatures were all near ambient because of the greater degree of atmospheric emission.

Because the field site values are so segregated, it is hard to see any trend occurring with the off glint angle unless the trends are looked for within each of the field site data groups. In Figure 3 the Wallops Island, vertical scanning section of the graph shows a slight decrease in radiance with increasing off glint angle. The opposite is true for the Wallops Island, horizontal scans where the values around 10 degrees off glint angle are greater than at 2 degrees. Regardless of which direction the radiance changes with off glint angle, it is obvious these changes are small.

Figure 4 graphs the radiance versus the sensor elevation where each plotted point has been assigned a symbol according to the following: a "1" means the point had a glint angle less than or equal to 3 degrees, a "2" means the point had a glint angle of 4 to 6 degrees, a "3" means the point had a glint angle of 7 to 11 degrees. A point with a symbol of "2" has been offset for better readability and the graph text indicates which field site the data was from. As in Figure 3 the data for each site is separate from each other. Again, because of the stratification of the data, it is difficult to compare field sites. However, for the data within each site it is clear that little or no variation is seen in the radiance due to sun glint. This was also evident from Tables 3 and 4 in which the radiance increased and decreased unpredictably with sensor elevation.

Figure 5 graphs the radiance standard deviation versus the off glint angle. The box symbol represents a point with a sensor elevation of 0 degree, and the number symbols represent a point with the negative of the sensor elevation. This figure does not have the separation among field sites that Figures 3 and 4 had although there are 3 columns at off glint angles of 2, 5, and 10 degrees which rise above the rest of the data. The data in these columns is from the vertical scans at Wallops Island (see Tables 3 and 4) and has a noticeably greater standard deviation than the rest of the data.

Table 6 lists the radiance needed at three different blackbody temperatures to produce a 1 degree Celsius change in the apparent temperature. The value at 0 degree Celsius was found by subtracting the radiance at -0.5 degree Celsius from 0.5 degree Celsius with the other values being found similarly. Using Table 6 with Figure 5, the radiance standard deviation range of 0.01 to 1.00 W m^{-2} sr^{-1} converts to a temperature standard deviation range of 0.02 to 2.21 degrees Celsius (using the 0 degree Celsius temperature as the basis for finding the radiance needed for a 1 degree Celsius change in temperature).

Note in Figure 3 that the radiances for the vertical scans at Wallops Island were the lowest of all the sites while the standard deviation radiance for the vertical scans was the highest of all the sites. Sun glint in the longwave, while not affecting the average radiance of the scene much, can have a more pronounced effect on the standard deviation. The effect is still small, however, because the standard deviation does not go above 2.3 degrees Celsius. In comparison, sun glint in the midwave had standard deviations up to 12 degrees Celsius. The standard deviation in the longwave falls off slightly with increasing off glint angle if only the vertical scan data points are compared, but no fall off is evident for the rest of the data.

Figure 6 graphs the radiance standard deviation against the sensor elevation. As in Figure 4, a symbol of "1" means that point has an off glint angle of less than or equal to 3 degrees. The symbols "2" and "3" mean off glint angles of 4 to 6 degrees and 7 to 11 degrees, respectively. The "2" symbol has been horizontally offset for readability. In this figure a very steep change occurs in the standard deviation with sensor elevation. Notice that points with standard deviations above 0.25 W m^{-2} sr^{-1} are all from the vertical scanning scenes (as seen in Tables 3 and 4). Points from the other scenes do not show as clear a variation. The increase in the standard deviation with decreasing elevation was seen only in the vertical scanning data. A review of the visible spectrum video showed a jagged border to the glint pattern. This may have been due to the particular "shape" of the water wave slopes for that day or possibly to several different currents in the water.

In Figure 7 the average radiance of each data section has been subtracted from the radiance of a blackbody radiating at the ambient temperature of the field site and the difference plotted against the off glint angle. The text in the graph indicates the data collection location. Notice that the y-axis range has been reduced from about 12.0 W m^{-2} sr^{-1} in Figure 3 to about 7.0 W m^{-2} sr^{-1} in Figure 7 because the radiance separation between sites has been decreased. The Toulon points may have had the lowest radiance difference in the figure because either the average radiance was very near the ambient temperature radiance or the meteorological data taken at Toulon was not representative of the atmospheric conditions over the water (Toulon was the only site for which radiosonde data was not available).

Figure 8 plots the ambient temperature radiance minus the average radiance against the sensor elevation, and, as in Figure 7, the data has less spread. As expected, Figures 7 and 8 show that the radiance difference varies less than the average radiance and that in the longwave the apparent temperature or radiance is affected more by the ambient temperature than by the sun glint.

The skew was another statistic used to measure the amount of sun glint in a scene. Positive skew indicates a skew or tail to the right and negative skew has a tail to the left. Positive skew would be caused by a small number of samples with a high radiance (sun glint) while negative skew would be caused by samples with low radiance (reflected sky). If sun glint greatly affected the distributions, the skew should always be a positive value. To investigate the sun glints affect on the skew, the skew for each scene section was calculated, the minimum and maximum skew for each section found, and the results compared. Often the minimum skew of a section was negative, and sometimes even the maximum skew of a section was negative. At other times the maximum skew for a scene section was as high as 2.5.

The skew of an entire scan was also calculated if the scan had no obstructions in it. Even these skews were highly variable and gave negative minimums and large positive maximums. Figures 9 and 10 are histograms that demonstrate the variability of the skew statistic for the longwave data set. Figure 9 has a relatively large skew (for this data set) of 1.26 and is a scan from Wallops Island at a 5-degree off glint angle and -1 sensor elevation. As described in the figure, the data points represent the actual histogram of the data while the solid line is a Gaussian curve with a mean of 20.408 W m^{-2} sr^{-1} and a standard deviation of 0.56 W m^{-2} sr^{-1}. The mean and standard deviation Gaussian parameters were calculated directly from the data. The y-axis in Figure 9 is the fraction of total points with a specific radiance. The area under the curve (for unscaled x-axis units) and the sum of the relative frequencies over all radiances are equal to one.

Figure 10 has a relatively small skew and was taken from Wallops Island data at a 2-degree off glint angle and -1-degree sensor elevation. The data points represent the histogram of the actual data, and the solid line is a Gaussian curve with a mean of 20.686 W m^{-2} sr^{-1} and standard deviation of 0.65 W m^{-2} sr^{-1} as calculated from the data. If sun glint seriously affected the data, it would be expected the 2-degree off glint angle skew would be larger than at 5 degrees, but these two scenes are at least one example of where that is not occurring. Notice that it does not take many points higher than the average radiance value to affect the skew. In Figure 9 only several points were needed above 23.0 W m^{-2} sr^{-1} to make the skew large and positive. It is not possible to verify if these higher radiance points were due to sun glint or to other IR sources.

CONCLUSIONS AND RECOMMENDATIONS

For the data taken with the BMAP sensor at Fort Walton Beach, Toulon, and Wallops Island, statistics such as the average and standard deviation radiance have shown a weak response to sun glint in the 8 to 12 micron region as expected for the sea states and sun elevations used in this report. This is in contrast to the strong influence of sun glint in the 3 to 5 micron region. Instead of sun glint, the ambient temperature dominates most measurements made in the longwave region. The sun glint caused little or no change in the average radiance when compared with the off glint angle or sensor elevation. The increase in the radiance standard deviation with decreasing sensor elevation was the only noticeable effect sun glint had on the statistics used. The skew, because it was often negative, also proved ineffective in detecting sun glint.

All available BMAP data of sun glint in the 3 to 5 micron and 8 to 12 micron regions has been examined. Future analysis of sun glint should continue with data from the Infrared Analysis, Measurement, and Modeling Program (IRAMMP) sensor which also contains sun glint in both the 3 to 5 micron and 8 to 12 micron regions and which has a slightly higher resolution and a larger FOV. Since the radiance measurement is so dependent on the ambient temperature, future analysis in the 8 to 12 micron region will require good radiosonde data along the line of sight. The radiosonde data can be used as inputs to LOWTRAN which will calculate the radiance due to the atmosphere. LOWTRAN along with sun glint models can be used to make radiance predictions of the ocean surface with higher sea states and different sun angles which can then be compared with the actual data.

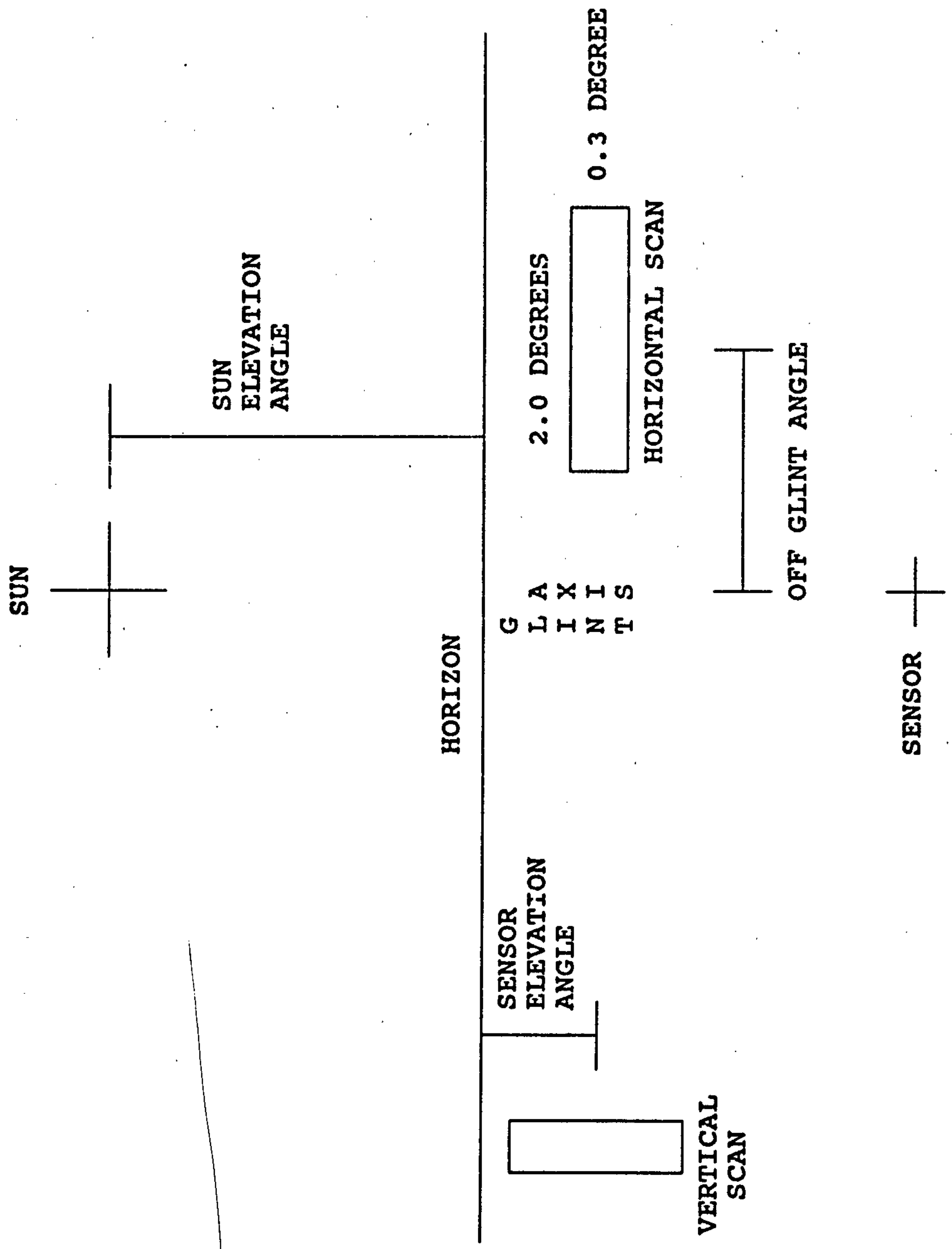


FIGURE 1. SCENE DESCRIPTION

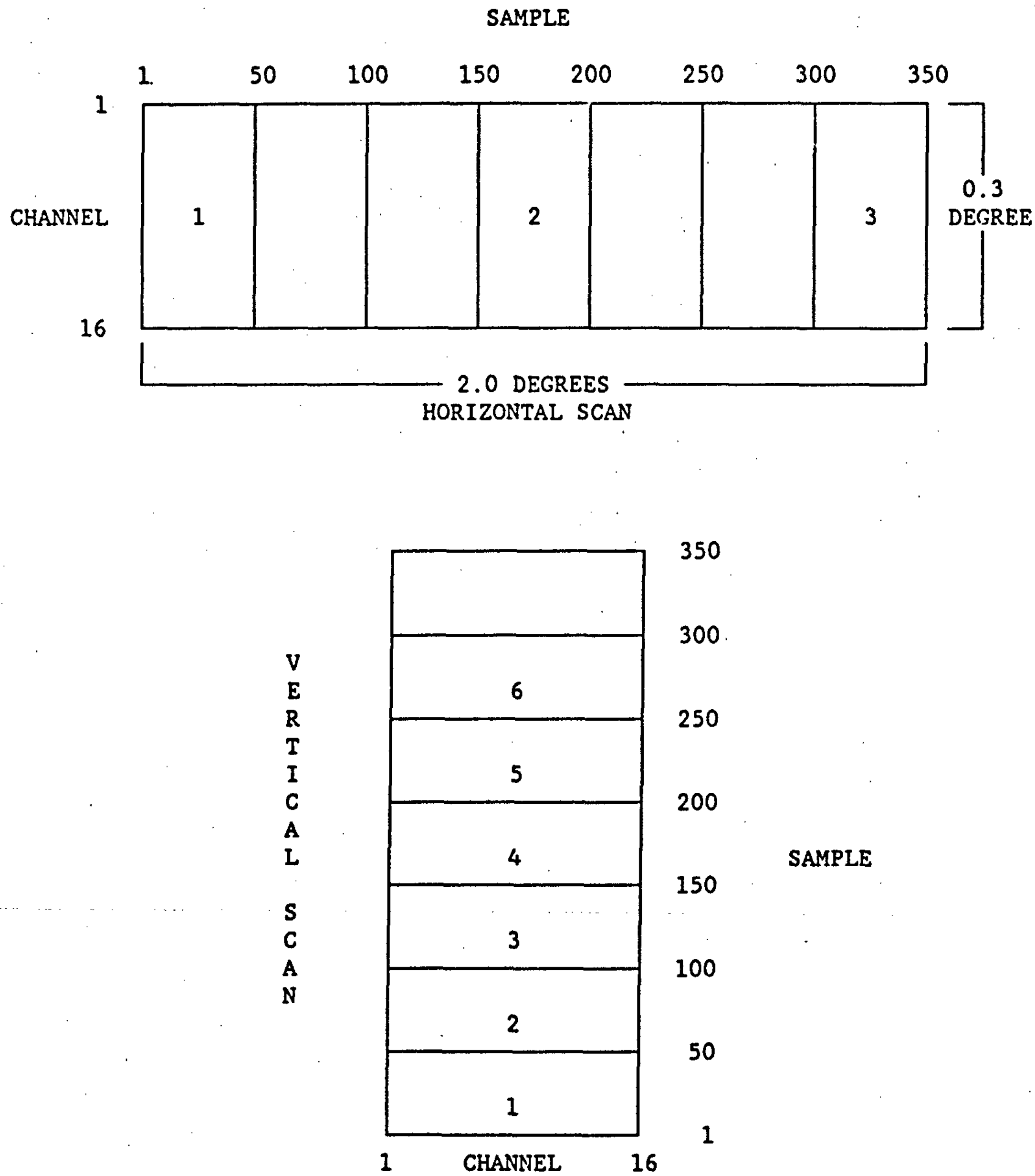
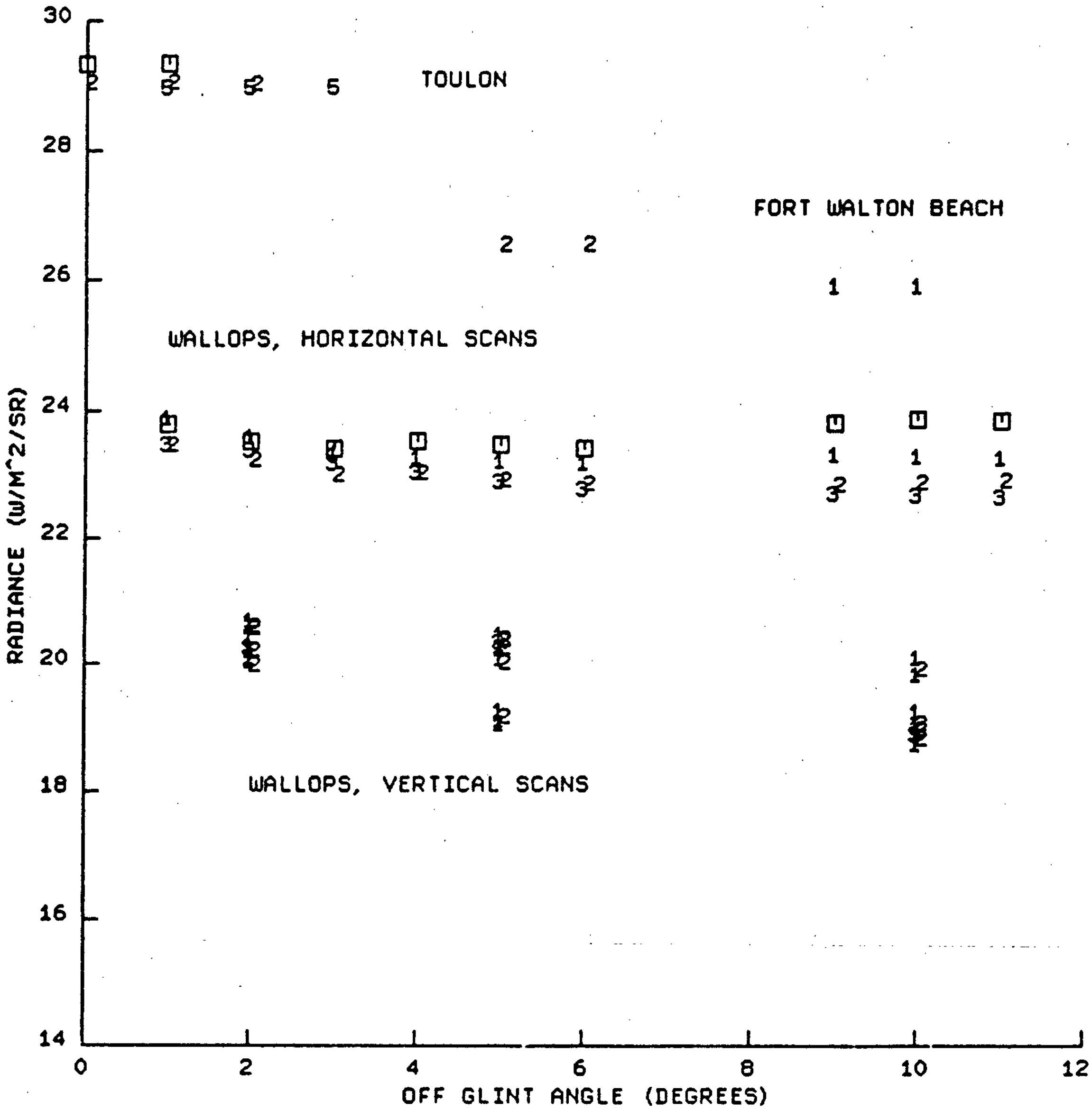
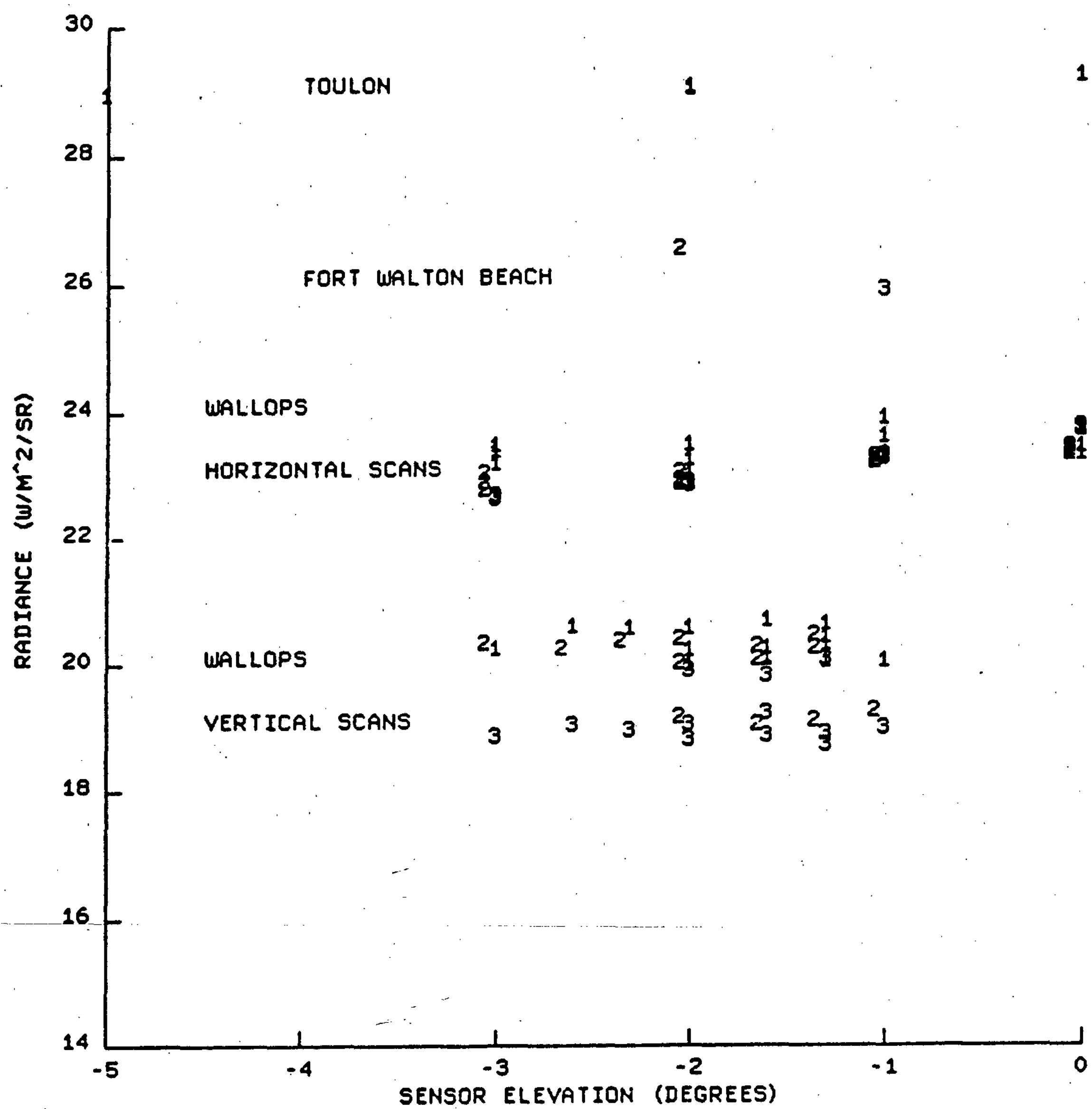


FIGURE 2. HORIZONTAL AND VERTICAL SCAN SECTIONS



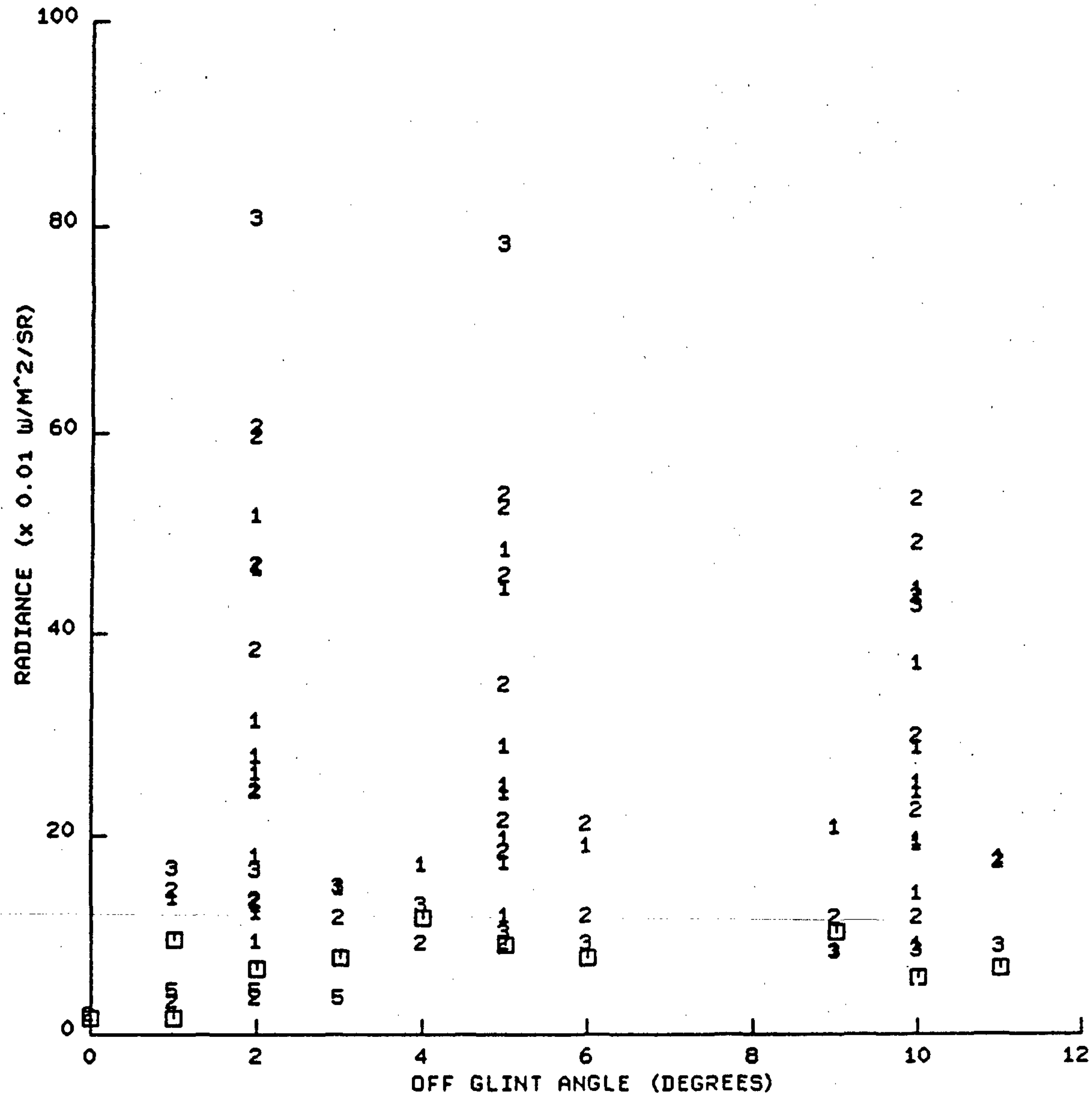
Box symbol equals 0 degree sensor elevation.
Number symbols equal negative of sensor elevation.
Symbol two has been offset for better readability.

FIGURE 3. AVERAGE RADIANCE VERSUS OFF GLINT ANGLE



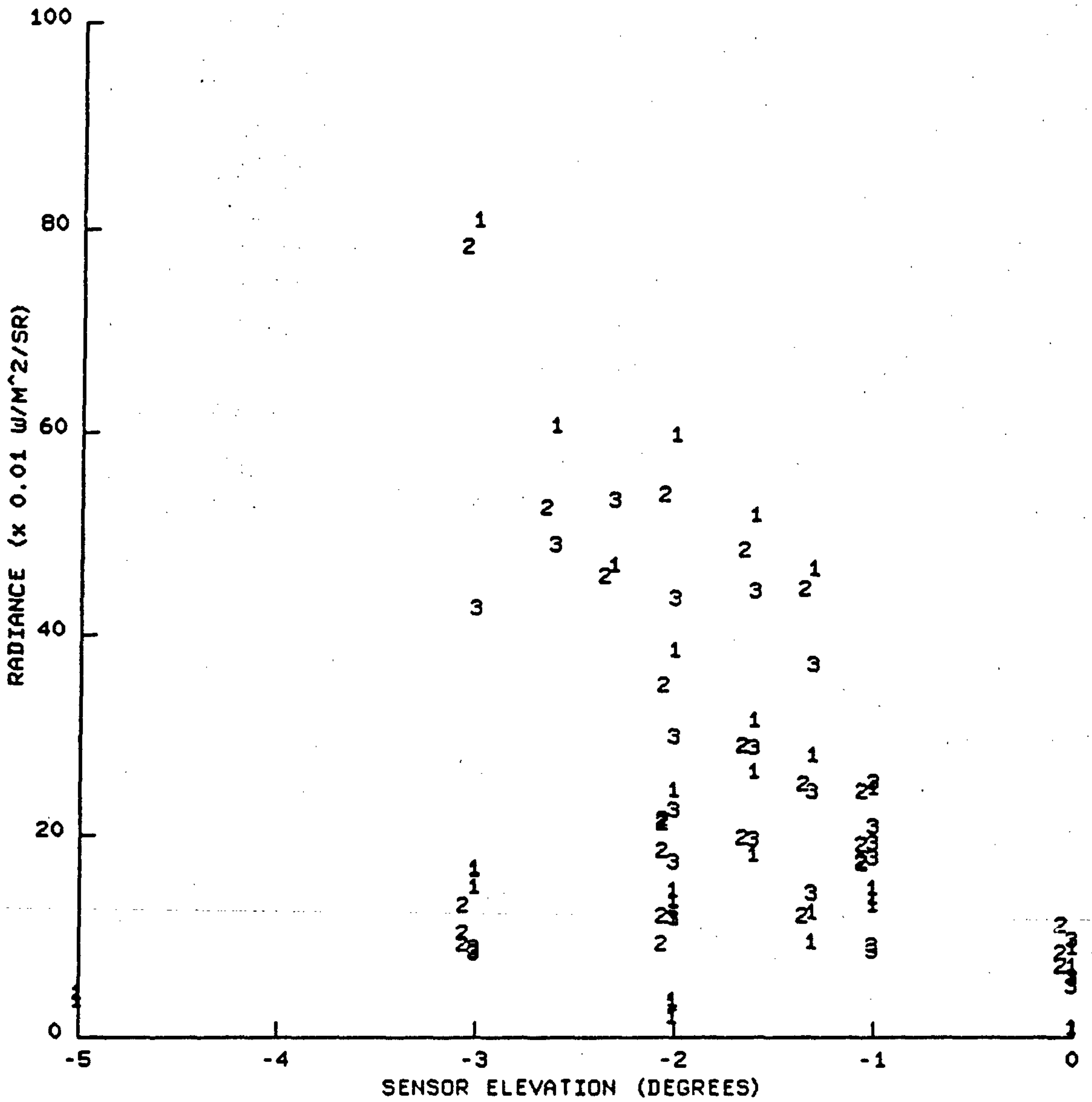
Symbol one equals a 0 to 3 degree off glint angle.
Symbol two equals a 4 to 6 degree off glint angle.
Symbol three eauals a 7 to 11 degree off glint angle.
Symbol two has been offset for better readability.

FIGURE 4. AVERAGE RADIANCE VERSUS SENSOR ELEVATION



Box symbol equals 0 degree sensor elevation.
Number symbols equal negative of sensor elevation.

FIGURE 5. STANDARD DEVIATION RADIANCE VERSUS OFF GLINT ANGLE



Symbol one equals a 0 to 3 degree off glint angle.
Symbol two equals a 4 to 6 degree off glint angle.
Symbol three equals a 7 to 11 degree off glint angle.
Symbol two has been offset for better readability.

FIGURE 6. STANDARD DEVIATION RADIANCE VERSUS SENSOR ELEVATION

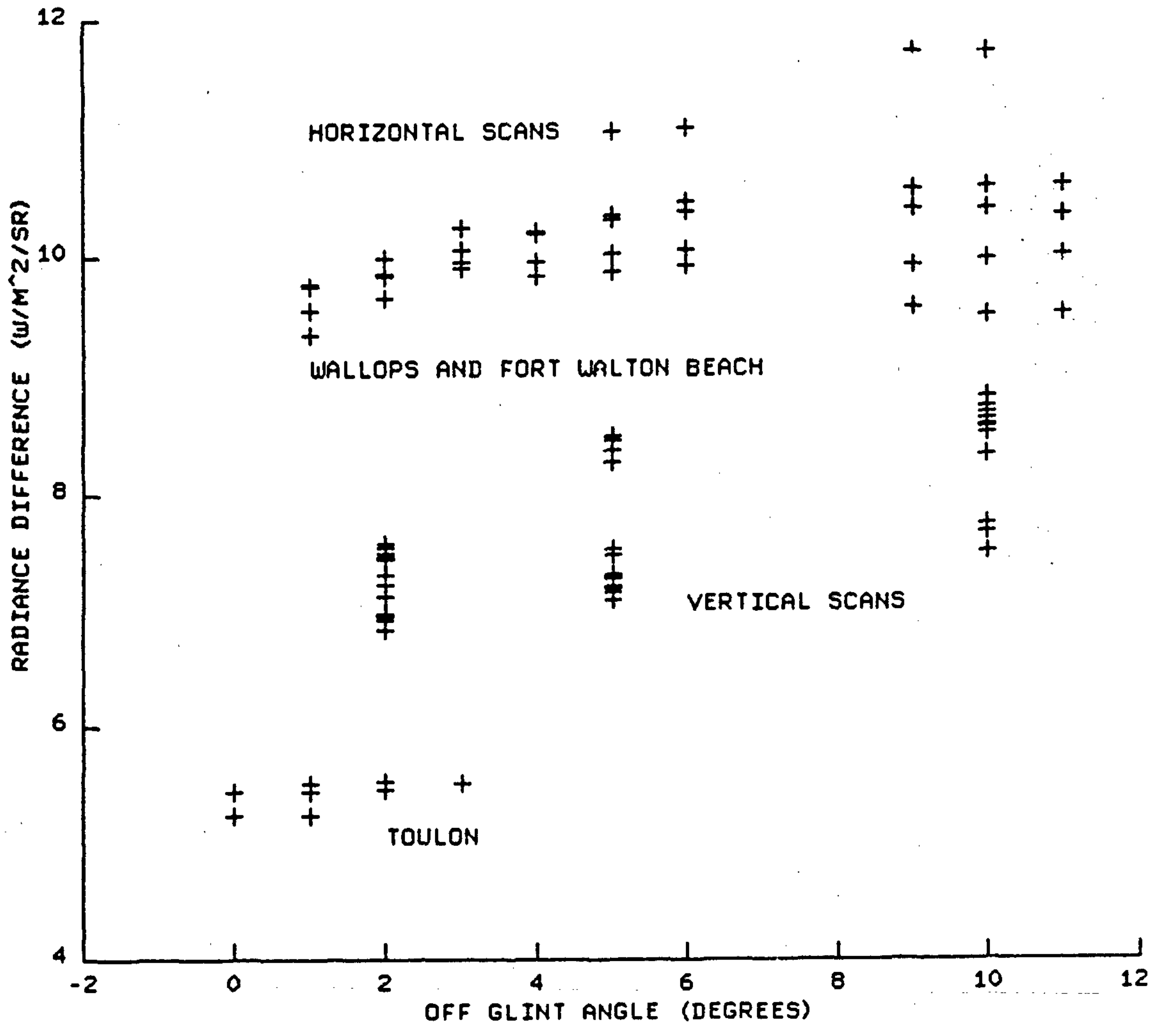


FIGURE 7. AMBIENT TEMPERATURE RADIANCE MINUS AVERAGE RADIANCE VERSUS OFF GLINT ANGLE

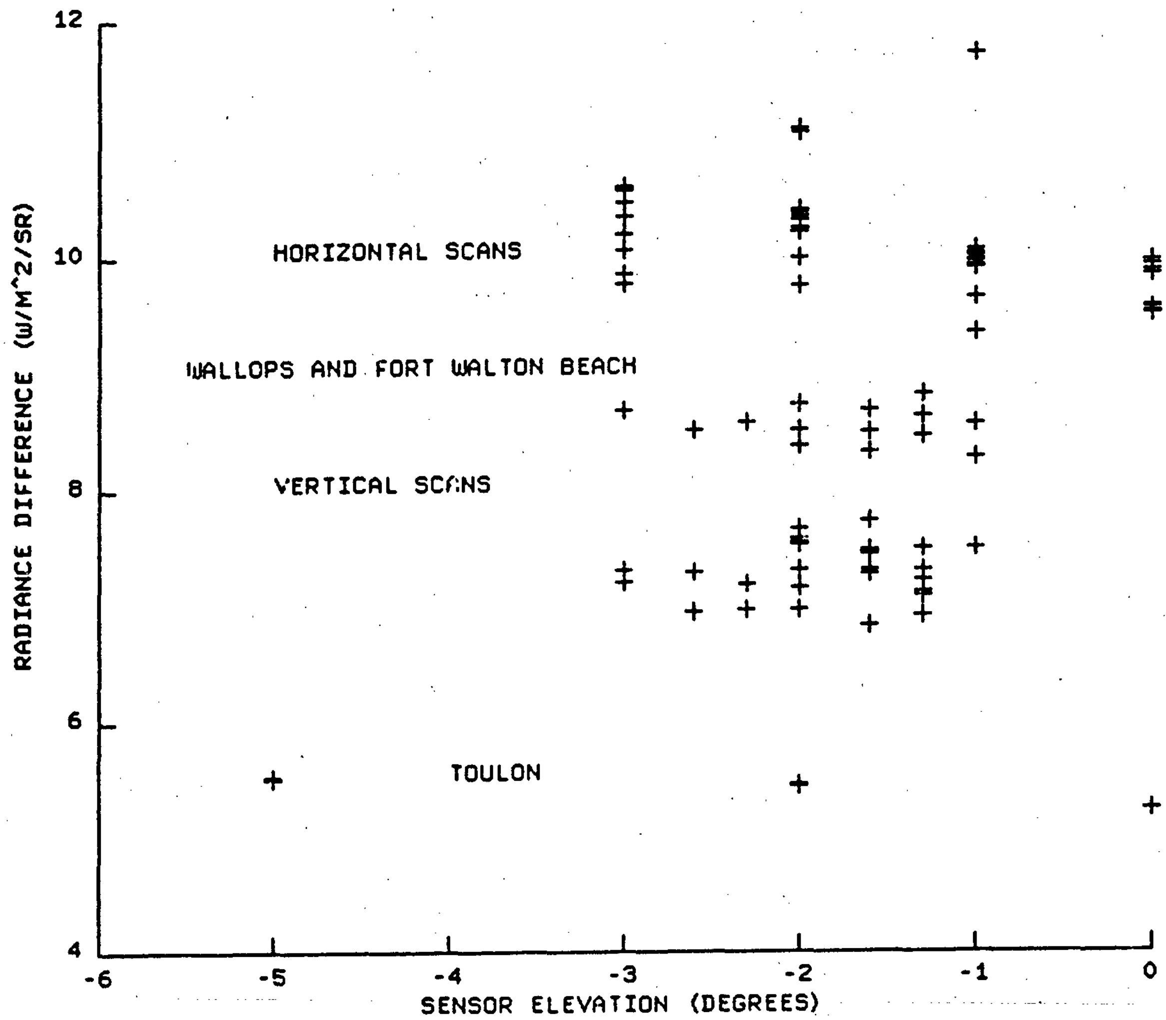


FIGURE 8. AMBIENT TEMPERATURE RADIANCE MINUS AVERAGE RADIANCE VERSUS SENSOR ELEVATION

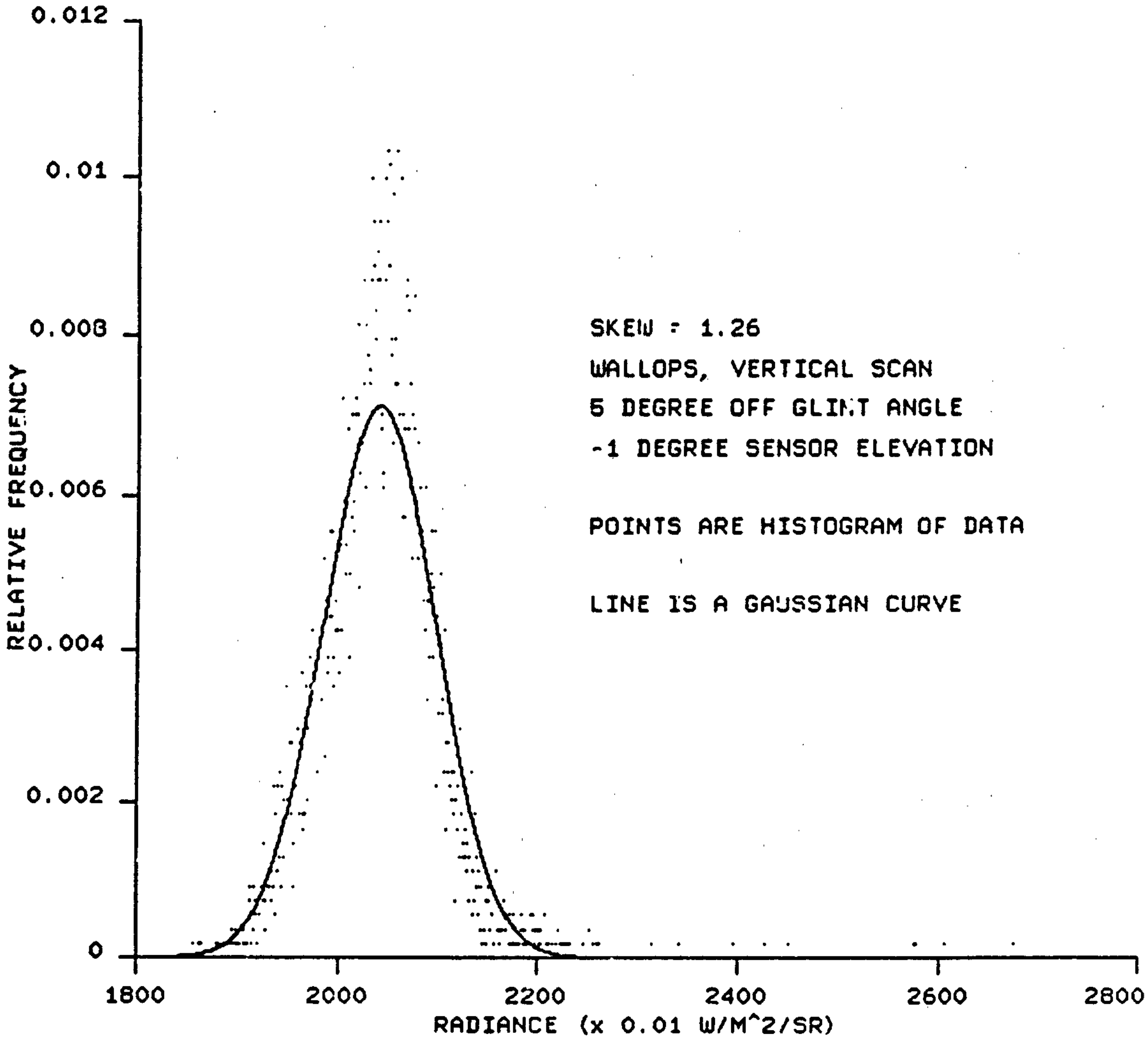


FIGURE 9. HISTOGRAM, HIGH SKEWNESS

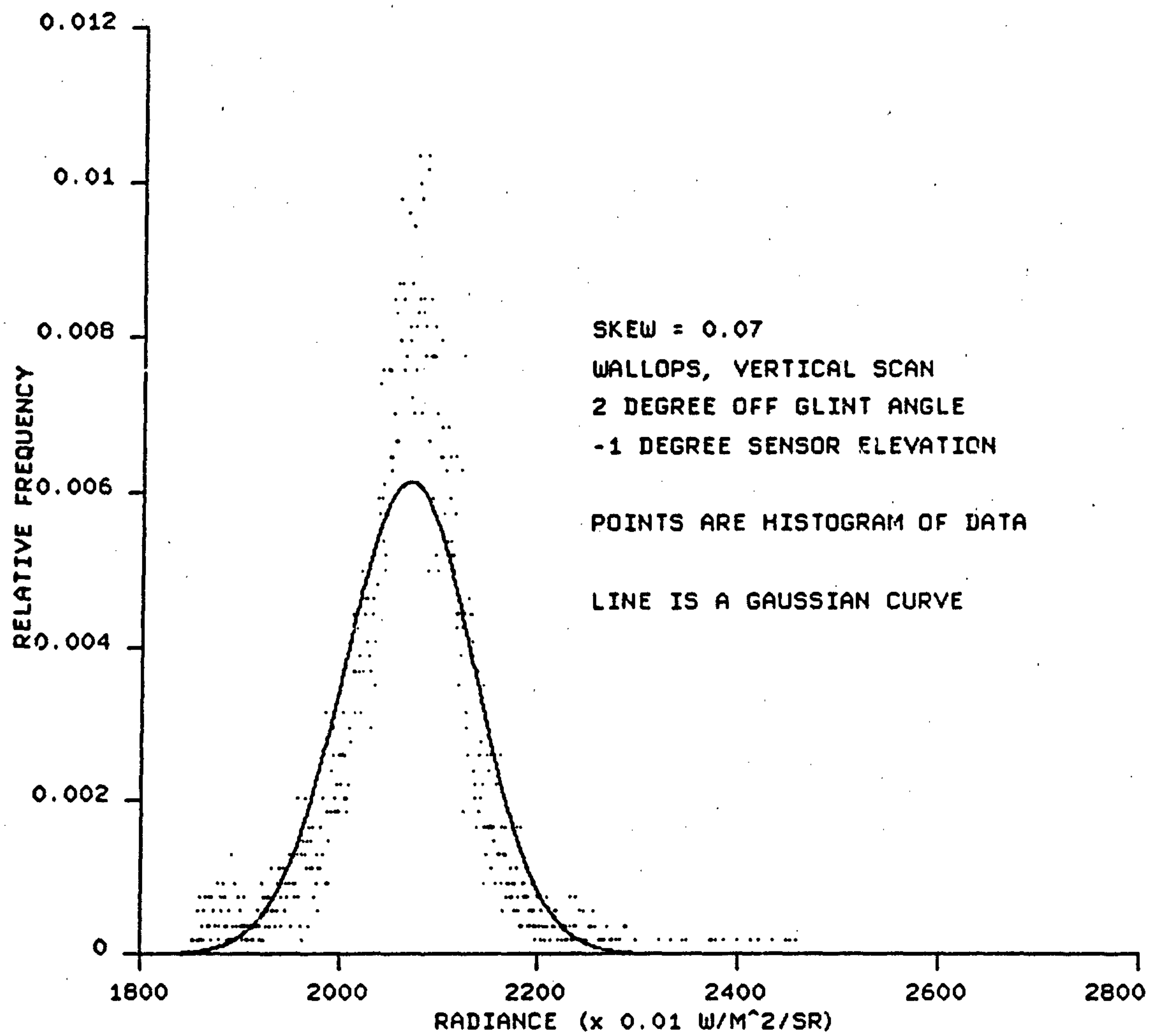


FIGURE 10. HISTOGRAM, LOW SKEWNESS

TABLE 1. METEOROLOGICAL CONDITIONS FOR EACH FIELD SITE

	FORT WALTON BEACH	TOULON	WALLOPS 30 MAY	WALLOPS 3 JUNE
AMBIENT TEMPERATURE (DEGREES C)	28.7	23.7	21.6	11.4
ABSOLUTE HUMIDITY (G/M^3)	15.7	12.4	16.0	5.5
WIND SPEED (KNOTS)	7.0	1.7	4.0	4.0
WIND DIRECTION (FROM TRUE NORTH)	200	N. A.	270	360

TABLE 2. PARAMETERS FOR EACH SCENE

LOCATION	OFF GLINT ANGLE (DEGREES)	SENSOR ELEVATION (DEGREES)	SUN ELEVATION (DEGREES)	SCANNING
TOULON	0	0	27	HORIZONTAL
TOULON	1	-2	30	HORIZONTAL
TOULON	2	-5	33	HORIZONTAL
WALLOPS	2	0	21	HORIZONTAL
WALLOPS	2	-1	23	HORIZONTAL
WALLOPS	2	-2	24	HORIZONTAL
WALLOPS	2	-3	25	HORIZONTAL
WALLOPS	5	0	22	HORIZONTAL
WALLOPS	5	-1	23	HORIZONTAL
WALLOPS	5	-2	24	HORIZONTAL
WALLOPS	5	-3	25	HORIZONTAL
FT. WALTON	6	-2	58	HORIZONTAL
FT. WALTON	9	-1	60	HORIZONTAL
WALLOPS	10	0	22	HORIZONTAL
WALLOPS	10	-1	23	HORIZONTAL
WALLOPS	10	-2	24	HORIZONTAL
WALLOPS	10	-3	26	HORIZONTAL

TABLE 2. (CONT.)

LOCATION	OFF GLINT ANGLE (DEGREES)	SENSOR ELEVATION (DEGREES)	SUN ELEVATION (DEGREES)	SCANNING
WALLOPS	2	0	20	VERTICAL
WALLOPS	2	-1	21	VERTICAL
WALLOPS	2	0	25	VERTICAL
WALLOPS	2	0	33	VERTICAL
WALLOPS	5	0	20	VERTICAL
WALLOPS	5	-1	21	VERTICAL
WALLOPS	5	0	34	VERTICAL
WALLOPS	10	0	21	VERTICAL
WALLOPS	10	-1	21	VERTICAL
WALLOPS	10	0	34	VERTICAL

TABLE 3. RADIANCE AVERAGE AND STANDARD DEVIATION BY SCENE SECTION (HORIZONTAL SCANS)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCE ($W\ m^{-2}\ sr^{-1}$)			MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION RADIANCE ($x\ 10^{-2}\ W\ m^{-2}\ sr^{-1}$)		
TOULON	2	29.33	29.350	29.37	1.45	1.625	1.80
0, 0, 27	3	29.32	29.350	29.38	1.51	1.615	1.72
TOULON	1	29.15	29.150	29.15	2.78	2.780	2.78
1, -2, 30	2	29.15	29.150	29.15	3.00	4.030	5.06
	3	29.13	29.135	29.14	4.26	4.330	4.40
TOULON	1	29.07	29.080	29.09	3.77	5.035	6.30
2, -5, 33	2	29.06	29.070	29.08	3.74	5.000	6.26
	3	29.07	29.075	29.08	3.98	4.300	4.62
WALLOPS	**	23.77	23.800	23.83	8.59	9.545	10.50
2, 0, 21	**	23.49	23.520	23.55	5.55	6.530	7.51
	**	23.37	23.405	23.44	6.02	7.700	9.38
WALLOPS	1	23.99	24.000	24.01	13.93	14.415	14.90
2, -1, 23	2	23.70	23.705	23.71	12.62	13.675	14.73
	3	23.44	23.455	23.47	14.17	15.370	16.57
WALLOPS	1	23.58	23.600	23.62	13.58	15.210	16.84
2, -2, 24	2	23.33	23.355	23.38	12.78	14.115	15.45
	3	23.07	23.115	23.16	11.05	12.345	13.64
WALLOPS	1	23.56	23.585	23.61	16.48	17.395	18.31
2, -3, 25	2	23.48	23.495	23.51	15.99	17.180	18.37
	3	23.27	23.295	23.32	14.32	15.590	16.86
WALLOPS	**	23.51	23.515	23.52	10.37	11.630	12.89
5, 0, 22	**	23.48	23.480	23.48	8.21	8.965	9.72
	**	23.41	23.425	23.44	6.49	7.745	9.00

* Parameters are off glint angle, sensor elevation, and sun elevation, respectively.

** Section composed only of channels below horizon.

TABLE 3. (CONT.)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCE (W m^{-2} sr^{-1})			MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION RADIANCE (x 10^{-2} W m^{-2} sr^{-1})		
WALLOPS	1	23.38	23.395	23.41	17.09	17.785	18.48
5, -1, 23	2	23.31	23.335	23.36	17.46	17.915	18.37
	3	23.26	23.300	23.34	19.10	19.625	20.15
WALLOPS	1	23.13	23.145	23.16	9.21	9.830	10.45
5, -2, 24	2	23.00	23.045	23.09	9.40	9.815	10.23
	3	22.91	22.975	23.04	11.52	12.535	13.55
FORT WALTON	1	26.61	26.650	26.69	20.60	22.115	23.63
6, -2, 58	2	26.56	26.630	26.70	20.41	21.865	23.32
FORT WALTON	2	25.81	25.985	26.16	8.69	9.040	9.39
9, -1, 60	3	25.73	25.985	26.24	9.04	9.610	10.18
WALLOPS	**	23.78	23.790	23.80	9.27	10.205	11.14
10, 0, 22	**	23.86	23.860	23.86	4.68	5.715	6.75
	**	23.82	23.835	23.85	5.64	6.545	7.45
WALLOPS	1	23.39	23.425	23.46	20.97	21.420	21.87
10, -1, 23	2	23.32	23.385	23.45	19.19	19.700	20.21
	3	23.24	23.340	23.44	17.69	18.205	18.72
WALLOPS	1	22.94	22.950	22.96	11.74	12.445	13.15
10, -2, 24	2	22.93	22.960	22.99	11.64	12.405	13.17
	3	22.96	23.000	23.04	16.79	17.935	19.08
WALLOPS	1	22.75	22.795	22.84	7.40	8.915	10.43
10, -3, 26	2	22.70	22.775	22.85	7.86	9.140	10.42
	3	22.66	22.750	22.84	8.47	9.475	10.48

* Parameters are off glint angle, sensor elevation, and sun elevation, respectively.

** Section composed only of channels below horizon.

TABLE 4. RADIANCE AVERAGE AND STANDARD DEVIATION BY SCENE SECTION (VERTICAL SCANS)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCE ($W\ m^{-2}\ sr^{-1}$)			MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION RADIANCE ($x\ 10^{-2}\ W\ m^{-2}\ sr^{-1}$)		
WALLOPS 2, 0, 20	1	20.27	20.340	20.41	36.14	39.010	41.88
	2	20.12	20.190	20.26	29.76	31.990	34.22
	3	20.08	20.165	20.25	26.11	28.545	30.98
	4	19.98	20.155	20.13	22.38	25.175	27.97
WALLOPS 2, -1, 21	1	19.95	20.355	20.76	65.69	81.465	97.24
	2	20.48	20.705	20.93	48.97	61.175	73.38
	3	20.55	20.680	20.81	36.46	47.410	58.36
	4	20.47	20.680	20.89	49.70	60.350	71.00
	5	20.64	20.815	20.99	40.94	52.434	63.93
	6	20.55	20.730	20.91	38.43	47.100	55.77
WALLOPS 2, 0, 25	1	20.02	20.085	20.15	21.67	25.090	28.51
	2	20.15	20.220	20.29	24.18	26.865	29.55
	3	20.47	20.530	20.59	9.44	10.120	10.80
WALLOPS 2, 0, 33	1	20.01	20.110	20.21	18.66	14.220	26.78
	2	20.26	20.355	20.45	15.06	18.570	22.08
	3	20.34	20.430	20.52	11.82	12.985	14.15
WALLOPS 5, 0, 20	1	19.20	19.280	19.36	28.85	35.585	42.32
	2	19.07	19.155	19.24	26.20	29.470	32.74
	3	19.15	19.205	19.26	23.11	25.700	28.29
	4	19.33	19.375	19.42	24.14	24.935	25.73
WALLOPS 5, -1, 21	1	20.09	20.455	20.82	65.93	78.845	91.76
	2	20.19	20.360	20.53	49.87	53.065	56.26
	3	20.35	20.465	20.58	41.03	46.335	51.64
	4	20.29	20.500	20.71	42.72	54.410	66.10
	5	20.20	20.390	20.58	44.22	48.995	53.77
	6	20.40	20.560	20.72	37.32	44.980	52.64

* Parameters are off glint angle, sensor elevation, and sun elevation, respectively.

TABLE 4. (CONT)

LOCATION AND PARAMETERS*	SECTION	MINIMUM, MIDRANGE, AND MAXIMUM AVERAGE RADIANCE ($W\ m^{-2}\ sr^{-1}$)			MINIMUM, MIDRANGE, AND MAXIMUM STANDARD DEVIATION RADIANCE ($x\ 10^{-2}\ W\ m^{-2}\ sr^{-1}$)		
WALLOPS	1	20.05	20.125	20.20	17.51	19.065	20.62
5, 0, 34	2	20.10	20.175	20.25	18.40	20.345	22.29
	3	20.32	20.355	20.39	11.96	12.635	13.31
WALLOPS	1	18.84	18.925	19.01	24.12	30.360	36.60
10, 0, 21	2	18.89	18.980	19.07	22.71	29.385	36.06
	3	18.78	18.835	18.89	20.44	24.835	29.23
	4	19.01	19.095	19.18	22.80	25.810	28.82
WALLOPS	1	18.62	18.975	19.33	28.23	43.275	58.32
10, -1, 21	2	18.86	19.150	19.44	34.00	49.470	64.94
	3	18.96	19.075	19.19	36.84	53.880	70.92
	4	19.00	19.145	19.29	26.12	44.190	62.26
	5	19.09	19.325	19.56	33.28	44.830	56.38
	6	18.91	19.020	19.13	28.48	37.480	46.48
WALLOPS	1	19.91	19.995	20.03	19.90	23.100	26.30
10, 0, 34	2	19.89	19.925	19.96	16.84	20.210	23.58
	3	20.11	20.170	20.23	14.01	14.865	15.72

* Parameters are off glint angle, sensor elevation, and sun elevation, respectively.

TABLE 5. CONVERSION OF RADIANCE TO APPARENT TEMPERATURE

TEMP(C)	RADIANCE ($W\ m^{-2}\ sr^{-1}$)	TEMP(C)	RADIANCE ($W\ m^{-2}\ sr^{-1}$)
-18	14.91	0	22.09
-17	15.26	1	22.55
-16	15.61	2	23.01
-15	15.98	3	23.48
-14	16.34	4	23.95
-13	16.72	5	24.43
-12	17.09	6	24.92
-11	17.48	7	25.41
-10	17.87	8	25.91
- 9	18.26	9	26.42
- 8	18.67	10	26.93
- 7	19.07	11	27.45
- 6	19.49	12	27.97
- 5	19.91	13	28.50
- 4	20.33	14	29.04
- 3	20.76	15	29.58
- 2	21.20	16	30.13
- 1	21.64	17	30.69

TABLE 6. RADIANCE NEEDED FOR A 1-DEGREE CHANGE IN TEMPERATURE

TEMPERATURE (C)	1-DEGREE RADIANCE CHANGE ($W\ m^{-2}\ sr^{-1}\ C^{-1}$)
-15	0.364
0	0.452
15	0.547

NOMENCLATURE

CHANNEL/DETECTOR:	one of the 16 detectors in the focal plane array.
GLINT AXIS:	axis formed by line between sensor and sun.
HORIZONTAL SCAN:	normal scanning mode; scans along azimuth.
OFF GLINT ANGLE OR GLINT ANGLE:	angle measured at sensor from glint axis to sensor azimuth.
RUN:	set of closely related scenes in which one parameter is incrementally changed, for example, sensor elevation.
SAMPLE:	one value from one detector.
SCAN:	image formed by one pass of the scanning mirror, usually a 16 by 371 array of points.
SCENE:	collection of scans in which continuous data was taken.
SENSOR AZIMUTH:	the angle from true north to sensor line of sight.
SENSOR ELEVATION:	the angle from the sensor line of sight to a line perpendicular to the forward face of the sensor when it's level. Zero degrees is usually slightly above the horizon.
VERTICAL SCAN:	sensor has been tipped on its side to produce scanning along elevation.

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Ocean sun glint data taken in the 8 to 12 micron region with the Background Measurement and Analysis Program's (BMAP) infrared radiometric sensor was compiled and reduced. The average radiance and standard deviation for each sensor scan was calculated and graphed against the sun glint angle and the sensor elevation.

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